Objective Probability in Everettian Quantum Mechanics

Wilson, Alastair

DOI:
10.1093/bjps/axs022

This is a preprint of a paper to appear in British Journal for Philosophy of Science.

Objective Probability in Everettian Quantum Mechanics

Alastair Wilson
University of Birmingham & Monash University
a.j.wilson@bham.ac.uk

ABSTRACT:

David Wallace has given a decision-theoretic argument for the Born Rule in the context of Everettian quantum mechanics (EQM). This approach promises to resolve some long-standing problems with probability in EQM, but it has faced plenty of resistance. One kind of objection (the 'Incoherence problem') charges that the requisite notion of decision-theoretic uncertainty is unavailable in the Everettian picture, so that the argument cannot gain any traction; another kind of objection grants the proof's applicability and targets the premises. In this paper I propose some novel principles connecting the physics of EQM with the metaphysics of modality, and argue that in the resulting framework the Incoherence problem does not arise. These principles also help to justify one of the most controversial premises of Wallace's argument, 'branching indifference'. Absent any *a priori* reason to align the metaphysics with the physics in some other way, we can adopt the proposed principles on grounds of theoretical utility. The upshot is that Everettians can, after all, make clear sense of objective probability.

1. Introduction

In recent work, David Wallace ((Wallace 2003), (Wallace 2006), (Wallace 2007), (Wallace 2010), (Wallace 2011)) has argued that a proof of the Born rule is available in the context of Everettian quantum mechanics (EQM) using techniques from decision theory, and that the proof involves no special metaphysical or epistemological commitments[1]. In particular, Wallace claims that issues surrounding the connections between probability and uncertainty and between probability and expectation can be bracketed while assessing the claim that the modulus-squared amplitudes of components of the quantum state (which I will refer to as their *weights*) should be identified with objective probabilities.

More is needed for a full account of objective probability in EQM, I shall argue, than Wallace acknowledges. Without the right connection between EQM and the metaphysics of modality, the argument fails to get a grip on its target, and a crucial premise lacks adequate motivation. The moral is that Wallace's hoped-for metaphysical neutrality cannot be sustained: a non-eliminative solution to the Everettian probability problem requires us to adopt substantive metaphysical principles. I will argue, however, that the principles in question are just as plausible as the most prominent alternatives; and that once they are granted, Wallace's argument can be vindicated, and the Everettian project strengthened.

The plan is as follows. Section 2 provides some background on the debate over probability in EQM, and on Wallace's argument. Section 3 describes two very different ways of combining the metaphysics of modality with the physics of EQM, which I call Individualism and Collectivism; I argue that we do not have *a priori* grounds for preferring one over the other, but should choose between them by considering their broader theoretical consequences. Individualism is further developed in section 4, where it is embedded in a metaphysical 'package deal' which I call Indexicalism. In section 5, I distinguish two versions of the 'Incoherence Problem' for probability in EQM, and argue that both versions of the problem rely on a tacit assumption of Collectivism. In the context of Indexicalism, the problems do not arise. Section 6 applies Indexicalism to the problem of justifying one of the key premises of Wallace's argument, Branching Indifference; I argue that Indexicalism provides significant additional support for this premise. Section 7 is a conclusion.

---

[1] Wallace's argument was inspired by a pioneering paper by David Deutsch ((Deutsch 1999), although there are several differences between their approaches. I will be focusing on the version of the argument that appears in (Wallace 2006), (Wallace 2007), and (Wallace 2010).

2. Setup

The 'probability problem' in EQM can be factored into three components:

- The Incoherence problem: what does objective probability consist in, according to Everettian quantum mechanics?
- The Quantitative problem: why should objective probabilities be given by the Born rule, according to Everettian quantum mechanics?
- The Epistemic problem: how does our statistical evidence confirm quantum mechanics, according to Everettian quantum mechanics?

The Incoherence problem has historically been the focus of discussion of Everettian probability, and it is easy to see why. In EQM, the fundamental laws of nature are deterministic. An initial quantum state, in combination with the unitary evolution, determines a complete emergent multiverse. What can objective probability possibly amount to in a theory like this?

Wallace's decision-theoretic argument presupposes a solution to (or a dissolution of) the Incoherence problem, and aims to solve the Quantitative problem. To be sound, the argument therefore requires not only that the premises it uses be true, but also that a successful response to the Incoherence problem be available. In this paper, I will first propose a solution to the Incoherence problem; I will then seek to provide a defence of what I take to be the most problematic of Wallace's premises in the light of that solution.

How the Incoherence problem and Quantitative problem are related to the Epistemic problem is a matter of controversy. Hilary Greaves and Wayne Myrvold (Greaves and Myrvold 2010) have attempted to solve the Epistemic problem independently of any solution to the other problems. Early work by Wallace (Wallace 2006) claimed that once the Incoherence and Quantitative problem are solved, the Epistemic problem is no more pressing for EQM than is the equivalent problem for any other probabilistic physical theory. More recent work by Wallace (Wallace 2011) has aimed to solve the Epistemic problem at the same time as solving the Quantitative problem. I favour Wallace's original response (Wallace 2006) to the Epistemic problem, but I will not discuss the issue further here; nor will I consider Wallace's more recent version of the decision-theoretic argument, which addresses the Epistemic and Quantitative problems together.

Wallace's strategy in addressing the Quantitative problem (as characterized in (Wallace 2010)) is to prove that a rational agent who knows that the quantum state has the structure that EQM attributes to it must allow weights to play the role of objective probabilities in his deliberations. This is a form of *probability coordination principle.* Such principles connect subjective probability (or *credence*) for rational agents, conceived of as a state of mind, with objective probability (or *chance*), conceived of as a state of the world. David Lewis' Principal Principle (Lewis 1980) and New Principle (Lewis 1994) are the best-known examples of probability coordination principles; but there are many others, usually adapted to different metaphysical conceptions of objective probability. For example, Carl Hoefer (Hoefer 2007) argues for one such principle in the context of his 'Third Way' Humean chances.

Some terminology: I will use the terms 'Everett world' and 'branch' interchangeably, to refer to the entities represented by decoherent histories that are part of a quasi-classical domain[2]. So far as possible I will remain neutral on whether Everett worlds overlap[3], in the sense of having segments in common; more on this below. It will be useful to refer to sets of Everett worlds meeting some macroscopic criterion (such as 'the device reads spin-up') as *outcomes*.

Wallace's argument aims to establish the following conclusion: that an agent who believes EQM and who is given a choice between two quantum interactions, defined as completely-specified unitary transformations of the quantum state, should choose the transformation which maximises total utility (as far as the agent now is concerned) over all the outcomes which result after the interaction, weighted according to the squared-amplitude (weight) of each outcome. This is not necessarily to say that the agent should choose whichever transformation maximises *expected* utility; whether squared-amplitude-weighted-total-utility amounts to the same thing as expected utility depends on how we think about expectation and uncertainty in the context of quantum interactions. This issue has generated much controversy, and I discuss it in section 5.

This concludes my brief sketch of the problems with probability in EQM. In the next section, I distinguish two approaches to combining the metaphysics of modality with the physics of EQM. The choice between these approaches will turn out to have significant consequences for the probability problem.

3. Individualism vs. Collectivism

The ontology of EQM can be aligned with the ideology of modal metaphysics in more than one way. In this section I contrast the prevalent approach in the literature, which I call *Collectivism*, with an approach –

[2] See (Saunders 2010a) for an introduction to the decoherent histories formalism and to its application to EQM.

[3] Note that this usage differs from that in (Wilson 2011a) where 'branch' is applied to mereologically overlapping entities, and 'world' only to non-overlapping entities. The present usage is closer to that of most other recent authors on EQM.

Individualism – which I think has been unfairly neglected. The presumption of Collectivism, I suspect, derives from a more general assumption about the relationship of physics and metaphysics, which I call the *One-Model-One-World Principle*, or OMOW for short. I argue that OMOW is unmotivated in the many-worlds context, and that nothing in the physics compels us to adopt either Individualism or Collectivism. That distinctively metaphysical choice should be made instead on grounds of overall theoretical utility.

Consider the following two principles connecting EQM with modal metaphysics:

Individualism:	If X is an Everett world, then X is a metaphysically possible world.
Collectivism:	If X is an Everettian multiverse, then X is a metaphysically possible world.

I take it that neither of these principles enjoys any obvious intuitive support. They both contain distinctively metaphysical technical terms, and it is implausible to think that we can determine the truth-values of such principles by direct inspection. However, Collectivism is the standard position among philosophers writing about EQM; why might this be?

Although it is not to my knowledge anywhere made explicit, I suspect that the following rather general principle about how physical theory relates to modal metaphysics has been influential in producing a presumption in favour of Collectivism:

OMOW	Each model of a physical theory represents exactly one metaphysically possible world.

I don't suggest that everyone who – implicitly or explicitly – adopts Collectivism must be committed to this principle. Other reasons for adopting Collectivism might involve the presumed causal or spatio-temporal connectedness of Everett worlds. But I do think that OMOW is lurking in the background of many discussions[4].

OMOW entails that each model of EQM corresponds to exactly one possible world. But models of EQM are complete multiverses; each model includes many histories, structures that we naturally want to think of as representing *alternatives* to one another. OMOW entails that these histories represent

[4] Tim Maudlin gives a clear statement of OMOW in a different context: 'Let us suppose (and *how can one deny it*) that every model of a set of laws is a possible way for a world governed by those laws to be.' (Maudlin 2007), p.67.

different parts of one single possible world; it precludes thinking of each history as representing a possible world in its own right.

I think that OMOW, while perhaps a natural assumption in the context of one-world physical theories such as classical mechanics, is false in the context of many-world physical theories such as EQM. By way of analogy, consider a physical theory that has as a model a Lewisian plurality of worlds, of the sort described by David Lewis (Lewis 1986). OMOW entails that the plurality would correspond to a single possible world; so taking OMOW to be an *a priori* truth requires taking the ontological postulates of Lewisian modal realism to be *a priori* false.

The multiverse of EQM has a strong structural resemblance to the pluriverse of Lewisian modal realism[5]. Since the natural way to interpret the connection between an ontology of Lewis-style worlds and modality involves a kind of modal realism, so the natural way to interpret the connection between an Everettian ontology and modality should involve a kind of modal realism. Hence, a proponent of EQM should prefer Individualism to Collectivism.

I don't take the argument just given against OMOW to be conclusive. But I do think that it gives us reason to be doubtful about the route to Collectivism which goes via OMOW, and hence that it gives us reason to consider further the potential merits of Individualism. In the next section, I supplement Individualism with some additional principles relating metaphysics to the physics of EQM; this package of views will then be applied to the probability problem in subsequent sections.

4. The Ingredients of Indexicalism

Individualism is silent on whether Everett worlds mereologically overlap one another; it leaves open the question of the status of propositions in EQM; and it says nothing about how actuality fits in to the picture. In this section, I combine Individualism with some additional principles connecting metaphysics with the physics of EQM. The resulting package deal, which I call *Indexicalism*, will provide all the resources that we need to tackle the probability problem in EQM.

[5] Exactly how close this resemblance is depends on whether we consider a diverging version of EQM or an overlapping version of EQM. (See section 4 for discussion of this distinction.) But the argument of this paragraph is in fact independent of the question of divergence versus overlap. (Lewis 1986) explicitly considered an overlapping version of his own modal realism. He rejected it, for much the same reasons that (Saunders 2010b), (Wilson 2011a) and (Wilson forthcoming) reject an overlapping version of EQM. But an overlapping modal realism is defensible (a position of this sort is defended by (McDaniel 2004) and the point remains that OMOW would rule out such a view *a priori*.

The first additional ingredient is the conception of Everett worlds proposed in (Saunders 2010b), in (Wilson 2011a) and in (Wilson forthcoming); these authors embrace a picture of Everett worlds as *diverging* rather than as *overlapping*, in the sense of David Lewis (Lewis 1986: 206). Overlapping worlds have initial segments in common; diverging worlds have qualitatively identical but numerically distinct initial segments. Whilst the 'branching worlds' metaphor is apt in the case of overlap, the 'parallel worlds' metaphor is more germane to divergence.

The diverging picture arises from a non-standard interpretation of the consistent histories formalism. The projection operators which feature in the consistent-histories formalism are normally interpreted as representing token property-instantiations. This allows that objects or events in two different histories can be numerically identical, resulting in a metaphysic of overlapping Everett worlds. But if the projection operators are instead interpreted as representing types of property-instantiations, then it becomes possible for events in distinct histories to only ever be qualitatively identical to one another, generating a metaphysic of diverging Everett worlds.

The choice between divergence and overlap is thus a choice between different ways of taking the formalism to represent reality; this choice is underdetermined by the formalism itself. As a result, neither an overlapping nor a diverging picture is forced on us by the physics; we must make the choice between them on grounds of overall theoretical utility and coherence.

I will argue in section 5 that, given that the choice between divergence and overlap turns on such general considerations, the diverging conception is to be preferred: the overlapping metaphysic gives rise to problems in accounting for the truth-values of future contingent statements. These arguments are also developed in more detail, by (Saunders 2010b), (Wilson 2011a), and (Wilson forthcoming). For clarity, however, I will build divergence into my framework from the outset.

The diverging version of EQM is relatively new; and it will no doubt be one of the more controversial of the assumptions appealed to in the course of this paper. Readers sceptical of diverging EQM, believing it to be incompatible with the mathematical formalism of QM, are directed in particular to (Saunders 2010b). Saunders there provides an explicit construction of a 'vector mereology' according to which superpositions of quantum histories – as represented by Hilbert-space vectors – come out as non-overlapping. I take this construction to demonstrate the consistency of divergence with EQM. In what follows, I will simply take it for granted that a diverging interpretation of the consistent histories formalism is legitimate.

Once we adopt Individualism, it is plausible to think that ordinary, contingent propositions – the sort of propositions that have non-trivial objective chances – can be identified with (or are at least isomorphic to) sets of Everett worlds. An initial plausibility argument for this identification goes as follows[6]:

1. Objective chances attach to propositions.
2. If objective chances are given by weights, then the bearers of objective chances are (or are isomorphic to) sets of Everett worlds.
3. Objective chances are given by weights.
4. Propositions bearing objective chances are (or are isomorphic to) sets of Everett worlds.

A semantics identifying chance-bearing propositions with sets of Everett worlds obviously has much in common with Lewis' treatment of propositions as sets of Lewisian worlds. For a proposition P to be true at the actual world, in the picture incorporating Individualism which I will develop, is for the actual Everett world to be a member of the set of Everett worlds P.

This theory of propositions is compatible both with conceptions of actuality according to which it is an absolute property of worlds (see e.g. (Bricker 2001)) and with the Lewisian conception of actuality as *indexical* in nature (see e.g. (Lewis 1970), (Lewis 1986)). In my view, the latter conception fits much more naturally with EQM.

Although Everett memorably insisted (in a note added in proof to his original article) that all branches were "actual", it is clear from the context that he took the terms 'actual' and 'real' to be synonymous with one another:

> From the viewpoint of the theory *all* elements of a superposition (all "branches") are "actual", none any more "real" than the rest.
>
> (Everett 1957)

It is entirely unsurprising that Everett did not consider the possibility of an indexical conception of actuality; this idea was only introduced into academic philosophy by Lewis, over a decade later. Consequently, now that we have such a conception, there is no reason to abjure it on Everett's authority. In what follows, I will argue that indexical actuality is in fact a key component in a satisfying Everettian response to the probability problem.

The following principles jointly comprise the view that I call Indexicalism:

[6] This formulation was suggested to me by Cian Dorr.

Divergence:	Everett worlds do not overlap; each macroscopic object and event exists in one Everett world only.
Individualism:	Distinct Everett worlds comprise alternative metaphysical possibilities.
Propositions-as-sets-of-worlds:	Ordinary contingent propositions are sets of Everett worlds – a proposition P is true at an Everett world w if and only if w is a member of P.
Indexicality-of-actuality:	Each Everett world is actual according to its own inhabitants, and only according to its own inhabitants.

In the next section, I will show how Indexicalism can dissolve the Incoherence problem in EQM.

5. Indexicalism and Incoherence

The Incoherence problem is the problem of making sense of non-trivial objective probabilities in a many-worlds scenario. In this section, I will divide the problem into two, and show how Indexicalism resolves each sub-problem. The first sub-problem concerns the application of objective probabilities to propositions; I will refer to this as the *Trivialization problem*. The second sub-problem has been more extensively discussed in the literature, and concerns the alleged unavailability in EQM of an adequate notion of decision-theoretic uncertainty. I think that this second sub-problem, which I call the *Uncertainty problem*, is in fact a special case of the Trivialization problem; but given its recent prominence, it will be helpful to treat the special case separately. I will argue that both problems are generated by a tacit assumption of Collectivism, and that they can both be resolved by a proper application of the Indexicalist framework.

i) The Trivialization Problem

At the heart of the Trivialization problem is the question of whether, in EQM, we can coherently assign non-trivial[7] objective probabilities to propositions, as we do in the context of an orthodox one-world metaphysics of objective probability.

Probabilities are necessarily probabilities of propositions. But, so the objection runs, given any quantum state, and the deterministic unitary state evolution, the future will be described, with objective probability one, by a

[7] By 'a non-trivial objective probability' I mean an objective probability other than zero or one.

highly specific proposition which entails the existence of countless Everett worlds. The total state of reality at any time and the laws of nature therefore jointly determine the whole of the multiverse, with probability one. All propositions entailed by this maximal proposition have probability one; all propositions inconsistent with it have probability zero. Objective probability is trivialized.

This objection to EQM has been around for a long time, and it has been made eloquently by Barry Loewer, amongst others:

> How are we to understand this measure? What does the measure measure? None of the familiar notions of probability seem appropriate. Clearly it cannot be construed as measuring the chances in a stochastic law... since [EQM][8] is a deterministic theory.
>
> (Loewer 1996) p.230

According to the Trivialization Problem, weights – which attach to individual Everett worlds and not to whole multiverses – are simply the wrong type of quantity to play the role of objective probabilities. If this is right, then Wallace's decision-theoretic argument, whatever else it might show, cannot be in any way relevant to objective probability.

Wallace has recently expressed moderate sympathy with the following swift dismissal of arguments of this sort:

> [F]ormally speaking the measure defined by mod-squared amplitude on any given space of consistent histories satisfies the algorithms for a probability. Indeed, mathematically the setup is identical to any stochastic physical theory, which ultimately is specified by a measure on a space of kinematically possible histories.
>
> (Wallace 2010) p.228

Unfortunately, critics of Everettian probabilities will not be prepared to go along with this. According to the line of thought which drives the Trivialization problem, weights are categorically *not* equivalent to a measure on a space of kinematically possible histories – since, so it is argued, any initial condition combined with the unitary evolution gives only a single (rather oddly-shaped) kinematically possible history – the multiverse itself.

Collectivism is essential to the Trivialization Problem. Since, according to Collectivism, distinct Everett branches are not alternative possibilities but co-

---

[8] Loewer actually addresses this criticism at the 'instantaneous minds view', a 'many-minds' theory due to Lockwood (Lockwood 1989). But it applies with equal force to an unmodified version of EQM.

actualities, objective probabilities are probabilities for ways that the entire multiverses might go, rather than probabilities for ways that individual Everett worlds might go. Collectivism therefore undercuts any attempt to bypass the Trivialization problem; to identify Everett worlds with kinematically possible histories is in effect just to adopt Individualism[9].

Individualism is not the only component of Indexicalism which is required to provide a proper response to the Trivialization problem. Since the bearers of objective probabilities are propositions, we require an account of propositions according to which the squared-amplitude measure is defined over them. Such an account is provided by the principle Propositions-as-sets-of-worlds, which is incorporated into Indexicalism. Propositions bear objective probabilities in virtue of the squared-amplitude measure being defined over the sets of Everett worlds with which the propositions are identified. The probability that P, on this picture, can be thought of as the probability that the actual Everett world is a member of the set of Everett worlds P.

The Indexicality-of-actuality component of Indexicalism is likewise required if objective probabilities are to be assigned to propositions in full generality. Among the propositions to which we need to assign objective probabilities are such propositions as 'the actual outcome will be spin-up'. But if 'actual' applies to the entire Everettian multiverse, then the phrase 'the actual outcome' fails to refer uniquely, since the multiverse contains many outcomes. According to Indexicality-of-actuality, 'the actual outcome' refers uniquely to the outcome in the Everett world of the speaker; consequently, the Everett worlds in which tokens of 'the actual outcome is spin-up' are true are just those Everett worlds which contain spin-up outcomes, as required.

This indexical treatment of propositions and of actuality faces a difficulty involving future contingents, which has featured prominently in the recent literature on Everettian probability[10]. On the overlapping metaphysical picture usually combined with EQM, distinct worlds have initial segments in common: agents facing impending quantum interactions are located in every world which emerges from the interaction. An agent about to conduct a spin measurement, it seems, is then located both in an Everett world where the result is spin-up *and* in an Everett world where the result is spin-down. Will the result be up or down? Everettians seem unable to make sense of this question: both results will occur. (Or perhaps better: each result will occur.)

[9] A parallel step is taken at the level of decision theory by Wallace and Greaves. Thus e.g. (Greaves 2007) stresses the importance of identifying 'states' in decision theory with histories (individualism), rather than with centered worlds (collectivism). My approach is to tinker with the metaphysics rather than with the decision theory.

[10] See, e.g., (Saunders 1998), (Greaves 2004), (Saunders and Wallace 2008), (Wilson 2011a).

This problem has no analogue in Lewisian modal realism, according to which agents are always world-bound and worlds do not mereologically overlap. And it seems to undermine the use of indexical actuality to ground objective probabilities for future contingent propositions. If I am both part of a spin-up Everett world and part of a spin-down Everett world, why aren't the probabilities of the actual outcome being spin-up and of the actual outcome being spin-down both equal to one?

Various solutions to the problem of future contingents in EQM have been proposed. Vaidman (Vaidman 1998) and Tappenden (Tappenden 2010) have sought to ground our present assignment of probabilities to future contingents in a future assignment of probabilities to past contingents. (Saunders and Wallace 2008) proposed two distinct solutions to the problem (although they did not clearly distinguish between them) – one involving a specific ('worm-theoretic') metaphysics of personal identity, the other involving a revisionary metaphysics of macroscopic objects in general. However, Wilson (Wilson 2011a) argues that both of the solutions suggested by Saunders & Wallace face significant difficulties. My favoured solution to the problem with future contingents is that proposed in (Saunders 2010b), in (Wilson 2011a) and in (Wilson forthcoming) which embraces a picture of Everett worlds as diverging rather than as overlapping. It is for this reason that Divergence has been incorporated into Indexicalism.

ii) The Uncertainty Problem

Although I think the Indexicalist response to the Trivialization problem is a fully general one, a special case of the problem is of particular interest: the case of our epistemic attitudes to chance-bearing propositions. A common objection made against EQM is that that it cannot allow for a kind of status that chance-bearing propositions about the future are alleged to have, dubbed 'objective uncertainty'[11] by Belnap & Mueller (Belnap and Müller 2010). Objective uncertainty stands to subjective uncertainty as objective chance stands to subjective credence; so if an agent knows that it is objectively uncertain whether P, then the agent is rationally required to be subjectively uncertain whether P even if the complete current[12] state of reality, and the dynamics governing the evolution of reality, are both known with certainty.

---

[11] Confusingly, Wallace and Greaves have used the term 'subjective uncertainty' for essentially the same notion; but I find Belnap & Mueller's terminology more appropriate, as it underlines that the uncertainty in question is not eliminated by an agent's non-indexical knowledge.

[12] Setting relativistic worries about absolute simultaneity aside makes no difference to the philosophical issue, and simplifies the presentation.

Objective uncertainty, it is usually claimed, is a straightforward feature of one-world stochastic theories, such as the GRW approach to quantum theory (Ghirardi et al. 1986); because of the stochasticity of the dynamics, in a GRW world even certain knowledge of the dynamics and the current state of reality could not provide us with certainty about what will happen next. The subject-matter of objective uncertainty in stochastic theories is just the actual future.

It has often been thought that objective uncertainty is unavailable in EQM, because of the deterministic nature of the unitary dynamics. For example, Hilary Greaves has argued as follows[13]:

> The [Subjective Certainty] intuition is that if an observer-stage knows both the relevant aspects of the objective description of the universe, and his own location within that universe, there is no room for uncertainty, subjective or otherwise; and, further, that (due to the determinism of the Everettian quantum dynamics and our assumption that the pre-fission observer-stage knows the initial state) Everettian branching meets this condition.
>
> (Greaves 2004)

In a similar vein, Huw Price (Price 2010) argues that without objective uncertainty Wallace's decision-theoretic strategy fails to gain any traction:

> I think it is worth stressing that the availability of an appropriate notion of uncertainty doesn't *emerge from* the DW argument, but is *presupposed by it.* So if we sceptics are challenged to say which of these axioms we disagree with, we have at least the following answer: we're sceptical about any axiom – e.g., Wallace's Dominance, for one – that presupposes an analogue of uncertainty. And we'll remain sceptical, until our opponents convince us that they have a notion that will do the job.
>
> (Price 2010) p.375

Thoughts such as this are frequently expressed by critics of EQM. And taking themselves to have established that there is no room for objective uncertainty in EQM, the critics typically go on to argue that there is no sense in which a fully-informed Everettian agent about to make a measurement can *expect* either to see one outcome or the other, but not both. Greaves, for instance, argues that an observer about to make a measurement should expect to see *each* outcome.

Wallace's preferred response to such worries is simply to deny that there is a conceptual connection between objective probability and objective uncertainty.

[13] Because she is presupposing Collectivism, Greaves uses the phrase 'the universe' to refer to an entire Everettian multiverse.

Although in earlier writings ((Wallace 2003), (Wallace 2006), (Wallace 2007), (Saunders and Wallace 2008)) he sought to provide a philosophical grounding for objective uncertainty in the face of quantum interactions, more recently (Wallace 2010), (Wallace 2011) he has concluded that no such grounding is necessary. Although he admits that it seems obvious that objective probability requires the possibility of objective uncertainty, this is taken to be a case where our pre-theoretic beliefs are unreliable:

> It is, to be sure, extremely *intuitively plausible* that probability requires [alternative possibilities, only one of which is actualised, and genuine uncertainty as to what the outcome is]. But it is hard to see why this matters. Intuition, absent supporting arguments, is no guide to truth, as twentieth century physics has made clear.
>
> (Wallace 2011) p.116[14]

I find this response unsatisfying. Although our pre-theoretic beliefs are not sacrosanct, and scientific discoveries have overthrown many of them, such cases tend to be cases where we have illegitimately extrapolated a correct belief about a familiar domain to an unfamiliar domain. An example: given that permuting two (discernible) cups of tea generates a distinct alternative possibility, we infer that permuting two (indiscernible) electrons in an antisymmetrized state generates a distinct alternative possibility. Because of the significant differences between cups of tea and electrons, it turns out that this inference is invalid despite being 'intuitive'. Despite what we would naively have assumed, indiscernible quantum particles do not manifest the same statistical behaviour as discernible cups of tea.

I suggest that this sort of extrapolation from the familiar to the unfamiliar is characteristic of cases where our pre-theoretic beliefs are unreliable. But no such illegitimate extrapolation seems to be going on in the case of the conceptual connection between objective probability and objective uncertainty. If EQM is correct, then what we ordinarily think of as objective probability is – and has always been – constituted by weights of Everett worlds[15]. And if this is so, then weights are not a new and unfamiliar phenomenon, in the face of which we must inevitably accept the breakdown of our probabilistic concepts; rather, they are a familiar phenomenon under a new and unfamiliar mode of presentation. As a result, denying that objective probability requires objective uncertainty involves

---

[14] References to Wallace's book manuscript are to the draft of 09/04/2010.

[15] By this I do not mean to exclude the possibility that processes not essentially involving branching - deterministic slot machines, for example - can also give rise to objective chances. The claim is only that many of the objective probabilities we recognise in ordinary life (such as those in weather forecasts looking many weeks ahead, for example) are at least partially constituted by Everettian branching. For a technical discussion of this claim, see (Zurek and Paz 1994).

denying obvious claims about the macroscopic realm; for example, that rational certainty that it will rain a year to the day from now is incompatible with rational belief that there is non-zero objective probability that it will stay dry. I therefore find Wallace's appeal to the unreliability of our pre-theoretic beliefs about probability unconvincing.

Accordingly, I think it was a mistake for Wallace to retreat from his earlier view that objective uncertainty is a pre-condition of making sense of objective probability. In holding that objective uncertainty is necessary for objective probability, I align myself both with many critics of EQM (e.g. (Albert and Loewer 1988), (Maudlin 1994), (Loewer 1996), (Price 2010)) as well as with many of its friends (e.g. (Saunders 2010b), (Greaves 2004), (Greaves 2007), (Greaves and Myrvold 2010)). All of these authors have seen an incompatibility between objective probabilities and EQM. Not all of them have responded to it in the same way, however; while critics have typically seen a fatal difficulty for EQM here, Saunders and Wallace have sought to provide an account of objective uncertainty in EQM adequate to underwrite objective probabilities. And Greaves has argued that abandoning objective probability need not spell disaster for EQM; in her own work, and in collaboration with Myrvold, she has argued that – despite not *being* chances – branch weights can play the role in inference and decision-making in branching theories that chances play in non-branching theories.

Not all Everettians take objective probability to require objective uncertainty. A line of thought stretching back to (Papineau 1996) maintains that the supposed conceptual link between uncertainty and probability is in fact inessential to the concept of probability; its abandonment it is seen as a legitimate – even an admirable – example of empirical discoveries leading us to revise our metaphysics[16].

If there really were no way to make sense of objective uncertainty in EQM, and if our choice was between abandoning EQM and abandoning certain apparently plausible claims about the nature of objective probability, then it would seem like a dangerous philosopher's conceit to urge that the physics, and not the metaphysics, should be modified. But the dilemma is a false one: Everettians can after all provide for objective uncertainty, by adopting Indexicalism and taking objective uncertainty to be indexical uncertainty.

Together, the principles incorporated in Indexicalism characterize coherent notions of uncertainty and expectation which pertain to ordinary contingent matters of fact. The subject-matter for objective probability and objective

[16] Views of this sort have recently been endorsed by (Wallace 2010) and (Tappenden 2010), and re-affirmed by (Papineau 2010).

uncertainty, for any agent A, is the nature of the Everett world of which A is a part – that is, of the Everett world which is actual for A. Even if A knows all the facts about the quantum state, A can retain indexical uncertainty – uncertainty about where in the multiverse A is. And since there are many Everett worlds which match A's Everett world perfectly up to any given time, even a complete specification of the past of A's Everett world does not fix its future. For realistic agents, Indexicalism renders objective uncertainty about the actual future ubiquitous in EQM, and thereby dissolves the worries about objective uncertainty and expectation that have been voiced by Loewer, Greaves, Price and others.

Of course, a truly omniscient agent, with complete knowledge of the quantum state *and* complete self-locating knowledge, would retain no uncertainty at all[17]; but Indexicalism at least allows that such an agent could have coherent thoughts about the future. A truly omniscient agent would still *expect* to see one course of events alone, the course of events in the Everett world she knows to be her own. Such agents would, it is true, have no need of objective probability according to the Indexicalist picture; but since they are physically impossible, and occur in no Everett world, this need not worry us unduly. Objective probability, we may say, is irreducibly self-locating.

What the Incoherence problem shows us, I think, is that we need to adopt the full package of Indexicalism in order to make proper sense of the application of objective probabilities to propositions describing distinct Everett worlds. Once we do so, we can agree with Wallace that weights play the role of a measure over a space of possible histories. If instead we presuppose Collectivism, as critics of EQM usually do (at least tacitly), then the only objective probabilities which could make sense in the context of EQM would be probabilities assigned to whole multiverses.

I argued in section 3 that there is no clear *a priori* reason to prefer Collectivism to Individualism. Since the former but not the latter leads to difficulties making sense of objective probabilities, Everettians who wish to make sense of non-trivial objective probabilities for outcomes of quantum interactions ought to prefer Individualism to Collectivism. And (assuming that Divergence is acceptable) it is a relatively natural step from Individualism to the full Indexicalist package.

---

[17] Note that this is true even for a one-world stochastic theory like GRW; a truly omniscient agent in a GRW world knows how all stochastic processes will in fact turn out, and so has no need for objective probabilities.

6. Indexicalism and Branching Indifference

Once we adopt Indexicalism, the first major obstacle to using Wallace's argument to ground objective probability in EQM – the Incoherence problem – is solved. Objective probabilities attach to propositions, as I have argued they must; and objective uncertainty can be cashed out as indexical uncertainty. What remains is to justify each of the axioms used in the proof. Wallace argues for these axioms in (Wallace 2010), and I think most of his defences of them are persuasive – with one notable exception. A crucial assumption in the proof – and one which is violated by some of the most influential proposed counterexamples to it – is *branching indifference*. In this section, I will explain this axiom and raise some objections to Wallace's arguments for it; I will then provide an argument for Branching Indifference which makes essential appeal to Indexicalism.

i) Introducing Branching Indifference

Here is Wallace's statement of *branching indifference*[18], which is supposed to be a principle of rationality in the Everettian context:

> BRANCHING INDIFFERENCE: An agent doesn't care about branching *per se*[19]: if a certain measurement leaves his future self[20] in N different microstates but doesn't change any of their rewards, he is indifferent as to whether or not the measurement is performed.
>
> (Wallace 2010) p.238

[18] Wallace intends the terminology of 'branching' to be neutral between overlap and divergence. For the purposes of this paper, I follow his usage.

[19] Wallace's use of the term '*per se*' here might seem worrying - even if we don't care about branching for its own sake, might we not nevertheless care about it because we believe it to be correlated with something we do care about, such as pleasure or pain? In fact, this possibility need not violate branching indifference; given Wallace's characterization of rewards, an agent who believes that branching is (somehow) correlated to pleasure or pain within branches will assign different distributions of rewards to branches in branching setups which differ physically only according to the amount of branching they involve. Such an agent will satisfy branching indifference, but will violate other axioms of Wallace's proof, such as 'diachronic consistency' or 'state supervenience'. So, despite the appearance of '*per se*' in its statement, branching indifference does not merely rule out taking branch number to be an end in itself; branching indifference rules out caring about branch number at all.

[20] This mention of 'future selves' is dispensable. Wallace's proof is intended to apply equally to acts where some of the post-interaction branches do not contain any 'future selves' of the agent; such branches can still be assigned 'rewards' by the agent at the present time.

To get a sense of what branching indifference involves, see Figure 1. Branching indifference requires a rational agent to be indifferent between the two branching setups illustrated. A and B are the rewards which attach to each branch; the numbers in boxes are the weights of each branch. The only difference between these setups is the number of branches corresponding to reward B; the range of available rewards, and their relative weights, is the same in each setup.

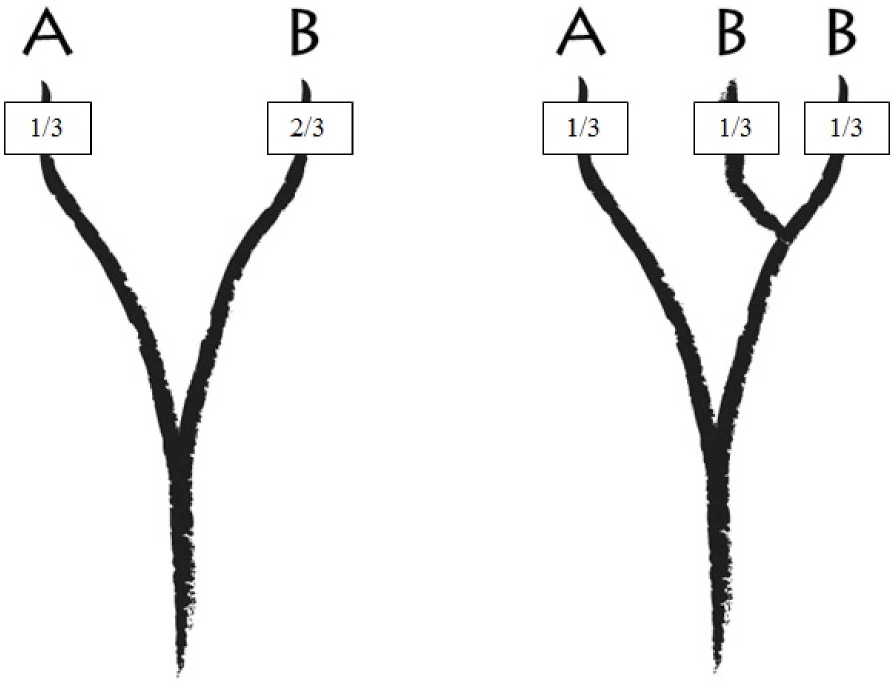

Figure 1

Wallace's defence of branching indifference has two strands. The first strand – the 'pragmatic defence' – denies that number of branches is something about which we could rationally have preferences, while the second strand – the 'non-existence defence' – maintains that branch number is not even well-defined. After discussing these approaches and raising some difficulties for them, I will describe how Indexicalism grounds a third defence of branching indifference which avoids these problems.

ii) The Pragmatic Defence of Branching Indifference

The pragmatic defence of branching indifference appeals to 'the limitations of any possible physically realizable agent':

> a preference order which is not indifferent to branching *per se* would be in principle impossible to act on: branching is uncontrollable and ever-present in an Everettian universe.
>
> (Wallace 2010) p.238

Prima facie, this defence looks incompatible with Wallace's further claim that there is no such thing as the number of branches. If branching occurs uncontrollably then it occurs to some degree or other. But it would be a mistake to push this point – the claim in question is phrased as a subjunctive, and Wallace is just attempting a *reductio* of the idea that there can be a preference order which is sensitive to amount of branching.

It is not clear that the *reductio* succeeds. That branching is ever-present does not prevent it being present to different degrees in different physical processes. Decoherence still holds many unknowns, and although no unproblematic scheme for quantifying degree of or amount of branching in a natural way has yet emerged, it does not seem out of the question that one might emerge in the future. Nor does it seem impossible that, according to some such scheme, the sort of choices we actually make might affect the amount of branching in our future. A thorough investigation of the details of decoherence that are relevant to quantifying branching is beyond the scope of this paper; but recall that one of the main sources of decoherence is the operation of classically chaotic processes. In the light of this, we might expect choices which affect the distribution of such processes across the universe to produce differential amounts of branching. In general, if choices happen to impact significantly on macroscopic variety in our future light cones, it seems at least possible that they will impact on the amount of branching in our futures.

Call the claim that there is no well-defined sense in which different physically possible acts produce different amounts of branching *branching homogeneity*. Even if branching homogeneity holds true, and our choices cannot in fact affect the total amount of branching, does it follow that we must be indifferent to branch number? Many things we value are out of our control, to a greater or lesser degree[21]. Preference orderings which are in principle impossible to act upon still appear to be coherent and possible preference orderings, pending positive arguments to the contrary. Wallace has in fact offered positive arguments of this sort in various places (e.g. (Wallace 2003), (Wallace 2007), (Wallace 2010). Here is an example:

> If we are prepared to be even slightly instrumentalist in our criteria for belief ascription, it may not even make sense to suppose that an agent genuinely wants to do something that is ridiculously beyond even their idealised capabilities. For instance, suppose I say that I desire (ceteris paribus) to date someone with a prime number of atoms in their body. It is not even remotely possible for me to take any action which even slightly moves me towards that goal. In practice my actual dating strategy will have to fall back on "secondary" principles

[21] (Albert 2010) emphasizes this point.

> which have no connection at all to my "primary" goal—and since those secondary principles are actually what underwrites my entire dating behaviour, arguably it makes more sense to say that they are my actual desires, and that my 'primary' desire is at best an impossible dream, at worst an empty utterance.
>
> (Wallace 2007) p.328

This passage endorses a functional conception of desire, according to which an agent's desires constitutively depend on their dispositions to action across the whole range of possible circumstances. This conception has the consequence that in cases where it is physically impossible for the agent's dispositions to action to be sensitive to some parameter – where that parameter is completely redundant in accounting for the agent's dispositions – then the parameter does not feature in the agent's preference ordering.

To see the consequences of the functional conception of desire for Wallace's defence of branching indifference, we must be sensitive to the distinction between the notion of a preference order over acts available to us – what we would prefer to do - and the more general notion of a preference order over future events – what we would prefer to happen. The functional conception of desire licenses us to restrict our attention to a preference order over physically possible acts. If some future event is a consequence of no possible act which is available to us, we can still have preferences defined over it in some (perhaps wistful) sense. But it is important to see that this would not be in conflict with branching indifference, which restricts only preferences over available acts.

An agent who knows which acts are physically possible for him, and who knows that each of those acts results in exactly the same amount of branching, cannot rationally prefer one act to another *on the grounds that it results in more (or in less) branching*. As a result, the assumption of branching homogeneity – that no physically possible act leads to any more or less branching than any other act – combined with the functional conception of desire, does seem to establish that compliance with branching indifference is a rational requirement.

However, if we do not grant the assumption of branching homogeneity, this defence of branching indifference will not work for us. Furthermore, not only will there then be difficulties with motivating branching indifference as a rational requirement on preference orders, but there will be some *prima facie* reasons to think that preference orders *violating* branching indifference may in certain circumstances be rationally required. Here is the motivating thought: if a state of affairs involves significant additional branching and thereby involves the coming into existence of significantly many additional people very like myself, why is this not exactly the sort of thing I *should* care about?

Consider an analogy: suppose we have an offer from God to create multiple copies of our solar system in far-flung corners of the universe. Even if these copies would be causally isolated from us, many prominent systems of population ethics still entail that we have reason to create them (as long as their lives would be reasonably happy, of course). Why is the situation significantly different in the Everettian case, when the copies to be created are not spatially distant, but instead are in different Everett worlds? What gives the Everettian a rational requirement to value the number of duplicates of herself in her own Everett world, but not to value the number of duplicates of herself across other Everett worlds? Call this line of thought the ethical objection[22].

The ethical objection has lurked in the background of many discussions of probability in EQM. It can be traced back to (Graham 1973), and more recently it has been expressed in various more or less uncritical appeals to the notion of what an Everettian agent can *care about* (for sophisticated versions of this line of argument, see e.g. (Greaves 2004), (Price 2010), (Kent 2010), (Albert 2010)). Those making such appeals typically first point out that EQM introduces a multiplicity of the sort of people, acts, events, or artefacts to which we ascribe normative value; they then argue that the way in which this multiplicity depends on our actions may have consequences for a rational agent's preference over acts. The argument is perhaps put most clearly by Huw Price:

> 'Where goes ontology, there goes possible preference.' Decision theory places no constraint on what agents care about, other than that it be *real*. The new ontology of the Everett view – the global wavefunction itself – thus brings in its wake the possibility of an agent who cares about *that*. Hence the challenge, in its most general form: by what right do we assume that the preferences of Everettian agents are driven by 'in branch' preferences *at all*?
>
> (Price 2010) p.380

Of course, the Born rule strategy that Wallace is attempting to prove allows that agents can sometimes care about global properties of the quantum state: the strategy is itself a rule for choosing between sets of branches generated by different unitary transformations. So it is not quite right to say that Wallace's argument assumes that Everettian agents are driven only by in-branch

---

[22] Variants of the ethical objection are possible which do not question branching indifference directly, but which interfere with the decision-theoretic strategy at different points. For example, (Price 2010) suggests that even if an Everettian must be indifferent to branch number, they need not be indifferent to outcome number that is, to the number of different types of world diverging from some interaction. In fact, this version of the ethical objection comprises a challenge to Wallace's 'diachronic consistency' axiom.

preferences. But branching indifference does at least rule out caring about one particular global property of the quantum state – branch number. Price's complaint seems to apply in full force here: if there is such a thing as branch number in the Everettian ontology, how can there be something incoherent or irrational about an agent who cares about it[23]?

The combination of a functional conception of intentional states and of the assumption of branching homogeneity does provide a way of ruling out preferences about branch number. To adopt the pragmatic defence of branching indifference is to insist that no physically possible agent's behaviour could ever make it correct to ascribe a preference order to the agent that is sensitive to branch number. But both of the components of this defence of branching indifference are controversial; and it would be better not to have to rest too much weight on it. In the next sub-section, I consider the other strand of Wallace's defence of branching indifference.

iii) The Non-Existence Defence of Branching Indifference

The main defence of branching indifference that can be found in Wallace's writings is that branch number is not well-defined, and hence that it cannot be a locus of normative value:

> There is no such thing as "branch count": ... the branching structure emergent from unitary quantum mechanics does not provide us with a well-defined notion of how many branches there are. All quantum mechanics really allows us to say is that there are *some* versions of me for each outcome.
>
> (Wallace 2010) p.255

This response can be combined with a wholesale rejection of the meaningfulness of talk about branch number[24]; alternatively, it can be combined with the thought that ascriptions of branch number, while meaningful in some

[23] The ethical objection can be made vivid by adapting Derek Parfit's 'repugnant conclusion' argument (Parfit 1984). The repugnant conclusion is that, given minimal and apparently plausible assumptions, for any finite population, no matter how large or how well-off its members, there will be a larger population whose members have lives only barely worth living but which is more valuable overall. Informally, quantity can always be made to override quality. The analogue of the repugnant conclusion in the Everettian case is that it will generally be rational for an Everettian to induce as much branching as possible, even at significant personal cost, as long as enough additional people are produced with lives even barely worth living.

[24] As in (Saunders 2005), whose derivation of the Born rule was explicitly premised on the stability of probabilities under changes in coarse-graining, and hence changes in branch number.

minimal sense, suffer from presupposition failure[25]. If the former route is taken, ascriptions of branch number are meaningless; if the latter route is taken, they are either meaningless or trivially false. Either way, they are never true. So, this strand maintains, once we properly grasp how branch number is an artefact of the mathematics, we will realize that there is simply no coherent way of incorporating it into our utility function.

I have argued elsewhere ((Wilson 2011b)) for an alternative treatment for ascriptions of branch number, which takes it to be *bivalently indeterminate*. Claims about branch number are always either true or false, but they need not always be determinately true or determinately false. This approach is compatible with various interpretations of the 'determinately' operator. *Prima facie*, the most familiar theories of vagueness – semantic indecision, epistemicism, and ontic vagueness – are all live options for Everettians[26].

If such a treatment of branch number is rejected, and the unpalatable view that claims about branch number are never true is embraced, then I think there can be little argument with branching indifference. But the cost of this move, as I have already emphasized, is high. It threatens to destroy the fragile grip we have on the worldview provided by EQM, by undermining the metaphors of branching and divergence which seem indispensable in explicating it. Indeed, the claim that 'how many people are there, unrestrictedly speaking?' has no true answer seems dangerously close to a *reductio* of any version of EQM which entails it[27]. There is accordingly good reason to look at alternative routes to justifying branching indifference.

An indeterminacy-based treatment of branch number does not by itself provide support for branching indifference. It might be tempting to think that when we know that it is indeterminate what the value of some quantity is, it is rationally required for us to be indifferent to that value. But this is not the case according to precisificational conceptions of indeterminacy, which allow us, for example, to determinately prefer being non-bald to being bald even if baldness admits of borderline cases. The point can be put as follows in the case of branch number: even if branch number is indeterminate, it is determinately greater than

---

[25] The classic examples of presupposition failure are cases of failed definite description, such as 'the current king of France is bald'. Such sentences need not be taken as meaningless; on a Russellian theory of descriptions they are (trivially) false, for example.

[26] For semantic indecision theories, see (McGee and McLaughlin 1995), (Dorr 2003); for epistemicism, see (Williamson 1996); for ontic vagueness, see (Barnes and Williams 2010).

[27] If there is no true answer to the question 'how many worlds?', then there is equally no true answer to the question 'how many people?', unless we are restricting our quantifiers to a particular world or worlds.

one[28]. This is already enough to generate a problem for branching indifference. If, *ceteris paribus*, copies of ourselves are to be valued, then a situation which determinately contains many copies of ourselves is (determinately) more valuable than one which contains fewer, even if it is indeterminate *how many more* copies the former contains than does the latter. This result follows straightforwardly from the logic of the determinacy operator, whether we appeal to epistemicism, to supervaluationism, or to any other bivalence-preserving precisification-based theory of vagueness to cash it out.

We might think that, regardless of the general metaphysical concerns we might have about it, the 'no-such-thing-as-branch-number' response undermines the decision-theoretic strategy's applicability. If claims about branch number are strictly meaningless, then can the idealized betting scenarios appealed to in Wallace's argument, in which branch number is well defined, adequately represent real-life scenarios? Wallace is sensitive to this concern, and has recently attempted (in (Wallace 2011) p. 183) to address it. There he gives an extension of the argument which shows that, for a given quantum decision problem, the choice of coarse-graining of the consistent history space can be varied without altering whether a given preference order definable over acts satisfies all of the axioms. For the sake of argument I shall assume that this response succeeds. My aim in this section is to argue that treating ascriptions of branch number as literally meaningless, or as never true, is not necessary to motivate branching indifference; I am happy to grant that it is sufficient.

If we supplement EQM with the functional conception of intentional states and with the assumption of branching homogeneity, or if we reject talk about branch number altogether, then we can motivate branching indifference. However, both of these routes to branching indifference may be found problematic. In the next section, I want to suggest an alternative way of defending branching indifference, a way which is compatible with an indeterminacy-based treatment of branch number and which takes Indexicalism as its main premise.

iv) The Indexicalist Defence of Branching Indifference

According to Indexicalism, other Everett worlds comprise alternative possibilities. Take any contingent proposition P that an agent might care about; according to Indexicalism, P corresponds to a set of Everett worlds. Introducing additional branching amounts to taking some Everett world w, which either is or is not a member of the set P, and generating multiple Everett worlds which are qualitatively identical to w up to some time t and different after t. But recall that the statement of branching indifference concerns a case in which all the

[28] Wallace tacitly recognises this when he acknowledges that there are 'some versions of me' for each outcome; note the plural.

things the agent cares about (i.e. the 'rewards') are the same at all of the post-branching Everett worlds. Thus, all the post-branching Everett worlds are in the set corresponding to P if and only if w is in that set. Therefore introducing additional branching will not change the truth-value of P at any world; and since P was an arbitrary proposition that an agent might care about, introducing additional branching never changes anything that an agent might care about.

Introducing additional branching of Everett worlds, where each newly-created Everett world contains the same reward as the parent Everett world, is a matter of multiplication of alternative token possibilities; but the number of alternative possibility types is unaffected. Given that the actual Everett world is in some set of Everett worlds characterized by a particular reward – that is, that a certain reward-specifying proposition is true at the actual world – we should be indifferent to how many other Everett worlds the salient set happens to contain. That is, we should be indifferent to how many ways there are for some reward-specifying proposition to be true. What we care about is invariably whether that proposition is true at the actual Everett world; about whether the reward in question is actual.

Wallace himself, in an earlier incarnation, has used an argument for branching indifference which is very similar to the one just given. There he presented it as depending not on Indexicalism, but on 'subjective uncertainty', which is essentially the thesis that objective uncertainty about the results of an upcoming measurement is available for an Everettian agent:

> Suppose that someone proposes to increase a million-fold the number of the agent's descendants who see heads: say, by hiding within the measurement device a randomizer that generates and displays a number from one to 1 million, but whose output the agent doesn't care about and probably never sees. Then from the SU viewpoint, this just corresponds to introducing some completely irrelevant extra uncertainty. For it is the central premise of the SU viewpoint that [a] process which from an objective standpoint involves branching, may be described subjectively as simply one with uncertain outcomes. In this case the objective description is "the agent branches into a million copies who see heads, and one copy who sees tails"; the correct description for the agent himself is "I will either see heads or tails, and I am uncertain as to which; if I see heads then I am further uncertain about the result of the randomiser reading — but I don't care about that reading".
>
> But it is a (trivially) provable result of decision theory that introducing "irrelevant" uncertainty of this kind is indeed irrelevant (*it is essentially the statement that if we divide one possible outcome into equally-valuable suboutcomes, that division is not decision-*

theoretically relevant). As such, from the SU viewpoint branching indifference follows trivially.

(Wallace 2006) (emphasis added)

This argument is plausible; but it trades both on the treatment of branches as alternative possible outcomes, and on the availability of a notion of objective uncertainty. I argued in section 5 that appeal to these resources requires Indexicalism. Much of the work in this argument is done by Individualism: without this principle the 'equally-valuable suboutcomes' are not alternative possibilities, so it makes no sense to be uncertain about which of them will occur, and the argument lapses[29].

The analogy between our choice of quantum act and God's offer to create copies of the solar system rested on a tacit assumption of Collectivism. The copies God proposes to create are in far-flung corners of the universe and so they would – if created – be part of the actual world. Collectivism entails that the people brought into existence by additional branching processes are likewise part of the actual world, and hence it seems that just as it is rationally possible (and indeed, perhaps rationally required) to value the copies God creates, it is rationally possible to value the additional people which result from additional branching of Everett worlds.

If we adopt Indexicalism, then the analogy between a choice of quantum act and God's offer lapses. The disanalogy between the cases is that the people God offers to create would be actual, while those brought into existence by additional branching would be (according to the Indexicality-of-actuality component of Indexicalism) merely possible. Since we should only care about actual things, and since Indexicalism entails that other Everett worlds contain only non-actual things, Indexicalism entails that we should not care about the other Everett worlds and their inhabitants.

Of course, even if Indexicalism is granted, branching indifference may still be rejected on the ground that an act's consequences for actuality do not exhaust its normative significance. The most plausible motivation for taking this line of resistance, I think, flows from the attractions of what Lewis (Lewis 1986), following Smart (Smart 1984), called a 'truly universalistic ethics'. That is a version of consequentialism according to which:

[29] Since the argument involves future branching, Divergence also plays a role: without divergence, we cannot coherently wonder about which future we will see, given that according to overlap we will see both futures. However, this feature of the argument appears to be dispensable; the argument works just as well when applied to a past branching event as to a future branching event.

> 'morality consists of maximising the total of good, absolutely regardless of where and to whom the good may accrue.'
>
> (Lewis 1986) p. 128

Lewis accepts that a truly universalistic ethics is undermined by his own modal realism, and it is likewise undermined by EQM. But so much the worse, declared Lewis, for a truly universalistic ethics:

> [I]f modal realism subverts only a 'truly universalistic ethics', I cannot see that as a damaging objection. What collapses is a philosopher's invention, no less remote from common sense than modal realism itself.
>
> (Lewis 1986) p.128

I think this response is exactly right[30]. Normative ethics is not a discipline which ought to be done entirely *a priori* – the possible shapes that an ethical theory can take will depend significantly on the background metaphysic with which a theorist is working. For example, metaphysical views such as idealistic solipsism or ontological nihilism seem likely to mandate a moral error-theory.

When applied to highly theoretical claims, such as candidate analyses of modality, our intuitions bear very little weight; what matters is how well the analyses perform (in conjunction with the rest of our worldview) in recovering our ordinary judgments. As with intuitions about the shape of an analysis of modality, our intuitions about the shape of an ethical theory are just not the right sort of considerations to trump metaphysical considerations. It is enough that some appropriate ethical framework can be provided which (in conjunction with the rest of our worldview) adequately underwrites our first-order moral judgments.

Global metaphysical theories should be allowed the use of whichever ethical theory fits best with their other elements, rather than having any such theory imposed *a priori*. For example, a form of consequentialism which ascribes normative value only to actual states of affairs seems perfectly viable in the context of an Indexicalist version of EQM, and it gives exactly the same first-order ethical consequences as the combination of a consequentialist truly universalistic ethics with a one-world physical theory. Everettians who adopt Indexicalism can therefore safely reject the ethical objection and uphold

[30] This is a defensive move. But Lewis thinks that modal realism actually provides a more natural home for our moral thought than a theory incorporating 'absolute actuality': 'An ethics of our own world is quite universalistic enough. Indeed, I dare say that it is already far too universalistic; it is a betrayal of our own particular affections. If my modal realism has any bearing at all on matters of value and morality, it pushes me towards common sense, not away.' (Lewis 1986), p.128.

branching indifference, without being obliged to commit both to branching homogeneity and to the functional conception of desire.

7. Conclusion

The conclusions which have emerged are that Indexicalism allows us to ground objective uncertainty in EQM; that Indexicalism allows us to vindicate treating the weights as an objective probability measure; and that Indexicalism provides new support for branching indifference. Absent any *a priori* argument for Collectivism, we are free to adopt Indexicalism on grounds of theoretical utility.

Of course, some will think that the cure that I propose (modifying principles connecting EQM with modal metaphysics) is worse than the disease (the apparent incompatibility of EQM with objective probability). Such people will be best off embracing the 'Fission Programme' endorsed by Greaves (Greaves 2004), by Papineau (Papineau 2010), and by Greaves and Myrvold (Greaves and Myrvold 2010). But I hope to have shown that the Fission Programme is not the only option for Everettians.

Acknowledgements

This research was supported by the Arts and Humanities Research Council; by University College, Oxford; by the University of Oxford Vice-Chancellor's Fund; and by the Australian Research Council. Thanks to Cian Dorr, Toby Handfield, John Hawthorne, Eleanor Knox, Oliver Pooley, Paul Tappenden, David Wallace, Robert Williams, and an extremely helpful referee for this journal. Especial thanks to Simon Saunders.

References

Albert, David (2010), 'Probability in the Everett Picture', in Simon Saunders, et al. (eds.), *Many Worlds? Everett, Quantum Theory, and Reality* (Oxford: Oxford University Press), 355-68.

Albert, David and Loewer, Barry (1988), 'Interpreting the Many Worlds Interpretation', *Synthese: An International Journal for Epistemology, Methodology and Philosophy of Science,* 77, 195-213.

Barnes, Elizabeth and Williams, Robert (2010), 'A Theory of Metaphysical Indeterminacy'. ¡http://www.personal.leeds.ac.uk/˜phljrgw/wip/theoryofmetaphysicalindeterminacy.pdf¿.

Belnap, Nuel and Müller, Thomas (2010), 'Branching with Uncertain Semantics: Discussion Note on Saunders and Wallace, 'Branching and Uncertainty'', *British Journal for the Philosophy of Science,* 61 (3), 681-96.

Bricker, Phillip (2001), 'Island Universes and the Analysis of Modality', in Gerhard Preyer (ed.), *Reality and Humean Supervenience: Essays on the Philosophy of David Lewis*.

Deutsch, David (1999), 'Quantum Theory of Probability and Decisions', *Proceedings of the Royal Society of London A,* 455, 3129-37.

Dorr, Cian (2003), 'Vagueness without Ignorance', *Nous-Supplement: Philosophical Perspectives,* 17, 83-113.

Everett, Hugh III (1957), ''Relative State' Formulation of Quantum Mechanics', *Reviews of Modern Physics,* 29, 454-62.

Ghirardi, GianCarlo, Rimini, A., and Weber, T. (1986), 'Unified dynamics for microscopic and macroscopic systems"', *Physical Review D,* 34, 470-91.

Graham, Neill (1973), 'The Measurement of Relative Frequency', in Bryce DeWitt and Neill Graham (eds.), *The Many-Worlds Interpretation of Quantum Mechanics* (Princeton: Princeton University Press).

Greaves, Hilary (2004), 'Understanding Deutsch's Probability in a Deterministic Multiverse', *Studies in History and Philosophy of Modern Physics,* 35B (3), 423-56.

--- (2007), 'On the Everettian Epistemic Problem', *Studies in History and Philosophy of Modern Physics,* 38 (1), 120-52.

Greaves, Hilary and Myrvold, Wayne (2010), 'Everett and Evidence', in Simon Saunders, et al. (eds.), *Many Worlds? Everett, Quantum Theory, and Reality* (Oxford: Oxford University Press), 264-305.

Hoefer, Carl (2007), 'The Third Way on Objective Probability: A Sceptic's Guide to Objective Chance', *Mind: A Quarterly Review of Philosophy,* 116 (463), 549-96.

Kent, Adrian (2010), 'One World Versus Many: The Inadequacy of Everettian Accounts of Evolution, Probability, and Confirmation', in Simon Saunders, et al. (eds.), *Many Worlds? Everett, Quantum Theory, and Reality* (Oxford: Oxford University Press), 307-54.

Lewis, David K. (1970), 'Anselm and Actuality', *Noûs,* 4, 175-88.

--- (1980), 'A Subjectivist's Guide to Objective Chance', *Studies in Inductive Logic and Probability, V2*.

--- (1986), *On the Plurality of Worlds* (Oxford: B. Blackwell).

--- (1994), 'Chance and Credence: Humean Supervenience Debugged', *Mind: A Quarterly Review of Philosophy,* 103 (412), 473-90.

Lockwood, Michael (1989), 'Mind, Brain and the Quantum: The Compound 'I'', *Cambridge: Blackwell*.

Loewer, Barry (1996), 'Comment on Lockwood', *British Journal for the Philosophy of Science,* 47 (2), 229-32.

Maudlin, Tim (1994), 'Quantum Non-Locality and Relativity', *Cambridge: Blackwell*.

--- (2007), *The Metaphysics Within Physics* (Oxford ; New York: Oxford University Press).

McDaniel, Kris (2004), '"Modal Realism With Overlap"', in Jackson & Priest (ed.), *Lewisian Themes*.

McGee, Vann and McLaughlin, Brian (1995), 'Distinctions Without a Difference', *Southern Journal of Philosophy,* 33 (suppl.), 203-51.

Papineau, David (1996), 'Many Minds are No Worse than One', *British Journal for the Philosophy of Science,* 47 (2), 233-41.

--- (2010), 'A Fair Deal for Everettians', in Simon Saunders, et al. (eds.), *Many Worlds? Everett, Quantum Theory, and Reality* (Oxford: Oxford University Press), 206-26.

Parfit, Derek (1984), *Reasons and persons* (Oxford Oxfordshire: Clarendon Press).

Price, Huw (2010), 'Decisions, Decisions, Decisions: Can Savage Salvage Everettian Probability', in Simon Saunders, et al. (eds.), *Many Worlds? Everett, Quantum Theory, and Reality* (Oxford: Oxford University Press), 369-90.

Saunders, Simon (1998), 'Time, Quantum Mechanics, and Probability', *Synthese: An International Journal for Epistemology, Methodology and Philosophy of Science,* 114 (3), 373-404.

--- (2005), 'What is Probability?', in S. Dolev A. Elitzur, and N. Kolenda (ed.), *Quo Vadis Quantum Mechanics?* (Berlin: Springer-Verlag), 209-38.

--- (2010a), 'Introduction', in Simon Saunders, et al. (eds.), *Many Worlds? Everett, Quantum Theory, and Reality* (Oxford: Oxford University Press), 1-52.

--- (2010b), 'Chance in the Everett Interpretation', in Simon Saunders, et al. (eds.), *Many Worlds? Everett, Quantum Theory, and Reality* (Oxford: Oxford University Press), 181-205.

Saunders, Simon and Wallace, David (2008), 'Branching and Uncertainty', *British Journal for the Philosophy of Science,* 59 (3), 293-305.

Smart, J. J. C. (1984), 'Ethics, Persuasion and Truth', *Boston: Routledge & K Paul*.

Tappenden, Paul (2010), 'Evidence and Uncertainty in Everett's Multiverse', *British Journal for the Philosophy of Science*.

Vaidman, Lev (1998), 'On Schizophrenic Experiences of the Neutron or Why We Should Believe in the Many-Worlds Interpretation of Quantum Theory.', *International Studies in the Philosophy of Science,* 12 (3), 245 – 61.

Wallace, David (2003), 'Everettian Rationality: Defending Deutsch's Approach to Probability in the Everett Interpretation', *Studies in History and Philosophy of Modern Physics,* 34B (3), 415-39.

--- (2006), 'Epistemology Quantized: Circumstances in Which We Should Come to Believe in the Everett Interpretation', *British Journal for the Philosophy of Science,* 57 (4), 655-89.

--- (2007), 'Quantum Probability from Subjective Likelihood: Improving on Deutsch's Proof of the Probability Rule', *Studies in History and Philosophy of Modern Physics,* 38 (2), 311-32.

--- (2010), 'How to Prove the Born Rule', in Simon Saunders, et al. (eds.), *Many Worlds? Everett, Quantum Theory, and Reality* (Oxford: Oxford University Press), 227-63.

--- (2011), *The Emergent Multiverse*.

Williamson, Timothy (1996), *Vagueness* (New York: Routledge).

Wilson, Alastair (2011a), 'Macroscopic Ontology in Everettian Quantum Mechanics', *Philosophical Quarterly,* 61 (243), 363-82.

--- (2011b), 'Modality Naturalized: The Metaphysics of Everettian Quantum Mechanics', (University of Oxford).

--- (forthcoming), 'Everettian Quantum Mechanics Without Branching Time', *Synthese*.

Zurek, W. H. and Paz, J. P. (1994), 'Decoherence, Chaos, and the 2nd Law', *Physical Review Letters,* 72 (16), 2508-11.